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for

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on

CONFORMATIONALLY STABILIZED CELL ADHESION PEPTIDES

by

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Field of the Invention

This application is a continuation-in-part of United States Patent application Serial No. 131,390, filed December 10, 1987, the entire specification of which is incorporated herein by reference.

This invention relates generally to peptides and more specifically to peptides which are involved in cell adhesion systems.

Background of the Invention

The adhesion of cells to other cells or to extracellular materials is important to the orderly development and functioning of cells in an organism. Cell adhesion is mediated by certain adhesive legands and corresponding receptors. Among such adhesive ligands are the glycoproteins fibronectin, vitronectin and collagen. All three contain the tripeptide sequence arginine-glycine-aspartic acid (Arg-Gly-Asp or R-G-D) which appears to function as the primary recognition site for receptors on the surface of cells binding to these molecules. When presented to cells as a peptide-covered surface, synthetic peptides containing the Arg-Gly-Asp sequence promote cell attachment in a manner similar to that of natural fibronectin or vitronectin. In solution, such peptides can inhibit cell attachment to a surface coated with fibronectin, vitronectin, collagen, the peptides themselves or some other adhesive protein having an Arg-Gly-Asp cell attachment site.

Several receptors have now been identified which recognize the Arg-Gly-Asp sequence of their respective ligands. While some of these receptors have affinity for only their specific ligand, others will interact to varying degrees with two or more ligands containing the tripeptide. It therefore appears that while the Arg-Gly-Asp sequence is sufficient for receptor recognition and binding, the

remaining amino acid sequence of the peptide may nonetheless be important to the specificity of the ligand-receptor interaction. The precise manner in which the remaining sequence affects binding has, thus far, remained elusive.

One view that has been held by some investigators in the field is that the specificity of a given adhesive protein for its receptor may depend on the presence in the adhesive protein of one or more receptor binding sites other than their Arg-Gly-Asp site. According to this view, the Arg-Gly-Asp site would be a shared binding site and the additional site or sites would be responsible for the specificity (See, for example, Yamada et al., (1987) Biochem. and Biophys. Res. Comm. 144:35; Wright et al., (1987) PNAS 84:1965). An alternative possibility is that the Arg-Gly-Asp sequence provides essentially all of the information for the receptor binding and that it is the conformation of this sequence that gives an adhesion protein its receptor specificity. The binding sites of various peptide hormones are known to be small (Rose et al., (1985) Adv. in Chemistry 37:1) but these peptides generally comprise only about 10 amino acids in total. In contrast, each of the two fibronectin polypeptide chains comprises over 2000 amino acids. The idea that the conformation of a single amino acid triplet could be important to the function of a number of different proteins carrying it is novel.

Synthetic peptides containing the Arg-Gly-Asp sequence are useful in that they can both promote and inhibit cell attachment. There are at least ten different adhesion receptors that are known or suspected to recognize an Arg-Gly-Asp sequence in one or more of the various adhesive proteins. Peptides that reproduce with reasonable accuracy the function of such adhesive proteins or specifically inhibit that function offer a tremendous potential for the manipulation of important physiological events such as thrombosis, metastasis, inflammation, wound healing, and rejection of prosthetic implants.

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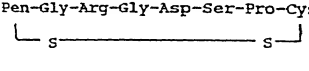
There thus exists a need for peptides having an amino acid structure that provides the optimum specificity for the receptor of interest. The present invention satisfies this need and provides related advantages as well.

Summary of the Invention

The present invention involves novel synthetic peptides which have high affinity and specificity for their receptors by virtue of restrictions on their stereochemical conformation. Such restrictions, or stabilizations, can be provided, for example, by cyclization, by inclusion into a constraining conformational structure such as a helix, by providing an additional chemical structure such as an amide or an enantiomer of a naturally occurring amino acids, or by other methods. Such peptides can have a range of numbers of residues, but preferably between 3 and 100, more preferably 7 to 30. In particular, there is provided a cyclic peptide having increased affinity and selectivity for the vitronectin receptor over that of linear, Arg-Gly-Asp-containing synthetic peptides. The affinity and selectivity of the cyclic peptide approaches that of natural vitronectin.

In one aspect, the invention comprises a peptide having about 10 amino acids in which a bridge is formed between amino acids surrounding the Arg-Gly-Asp sequence. A suitable structure is



The peptide may have about 1 to 4 amino acids between the Arg-Gly-Asp sequence and those residues forming the bridge. The bridging residues may be, for example, penicillamine and cysteine, or other amino acids capable of forming a bridge, such as a disulfide bridge.

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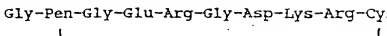
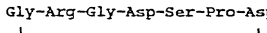
Another suitable structure is

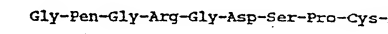


Alternatively, the peptide may be cyclerized through a peptide bond between amino acid residues. An appropriate structure is



The present invention provides evidence that, rather than the specificity of adhesion ligands residing in distinct binding sites outside the Arg-Gly-Asp site, such specificity results from the conformational structure imposed on the Arg-Gly-Asp sequence by the structure of the remaining peptide. At the practical level, the invention demonstrates that a conformationally restricted Arg-Gly-Asp-containing peptide can have different receptor specificity and higher binding affinity than its unrestricted counterpart. This demonstration permits the synthesis of other Arg-Gly-Asp conformations with variant receptor specificities and affinities.

The stabilized peptides of the present invention have various applications relating to their cell-adhesion properties. In one embodiment, for example, where the peptide structure is



the peptide has increased affinity for the vitronectin receptor and decreased affinity for the fibronectin receptor over that of linear synthetic Arg-Gly-Asp-containing peptides and may therefore be effectively used to inhibit the binding of vitronectin receptor-containing cells to a substrate for cell culture. Alternatively, the stabilized peptide may be usefully employed to promote

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adhesion of cells expressing the vitronectin receptor by, for example, coating cell culture substrates. Additionally, the stabilized peptide may be used to coat materials for in vitro implantation, such as prothesis, where cell attachment is desired.

Brief Description of the Drawings

The present invention will be described in connection with the accompanying drawings in which:

FIGURE 1 is a graph of HPLC analysis of a crude preparation of cyclic peptide (a); and purified cyclic peptide (b).

FIGURE 2 is a graph illustrating adhesion of normal rat kidney cells to fibronectin and vitronectin in the presence of a cyclic and a linear peptide having the same amino acid sequence.

FIGURE 3 shows the sequence of the peptide of Example III and the recovery of its degradation products recovered by automated Edman degradation.

FIGURE 4 records the change in optical rotation caused by a solution of the peptide of Fig. 3, as a function of increasing temperature, indicating its restricted conformation at the lower temperature.

FIGURE 5 is an axial projection of the peptide of Example IV. Those residues above the dotted line are lipophilic while those below the line are hydrophilic.

FIGURE 6 is a schematic representation of the cyclic peptide synthesized in Example VI.

Detailed Description of the Invention

As used herein, the term "conformationally stabilized"

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or "conformationally constrained" refers to limitations imposed on the number of possible stereochemical structures which a peptide may assume. In the context of the present invention, such limitations are imposed on the conformation of the Arg-Gly-Asp binding site and result from the presence of chemical structures surrounding the binding site which limit the possible structural conformations of the binding site to less than those assumable by the tripeptide sequence alone. Such conformationally stabilized Arg-Gly-Asp-containing peptides still exhibit binding activity with at least one receptor. "Surrounding chemical structures" may refer either to amino acids or other chemical moieties, and may refer both to those moieties lying immediately adjacent the binding site as well as those separated from the binding site itself by the presence of intervening amino acids. The term "amino acids surrounding the Arg-Gly-Asp sequence" refers both to residues adjacent to the Arg-Gly-Asp sequence as well as to residues separated from the Arg-Gly-Asp sequence by intervening residues.

As used herein, references to "Arg-Gly-Asp containing peptides" are intended to refer to peptides having one or more Arg-Gly-Asp containing binding sites which may function as binding sites for a receptor of the "Arg-Gly-Asp family of receptors", i.e., those recognizing and binding to the Arg-Gly-Asp sequence. While the Arg-Gly-Asp sequence has been found to necessarily be invariant in order to retain the binding activity, the composition of the remaining peptide as well as any other chemical moiety present in conjunction with the peptide may vary without necessarily affecting the activity of the binding site. Where specific chemical structures or sequences beyond the Arg-Gly-Asp sequence are presented, it is intended that various modifications which do not destroy the function of the binding site are to be encompassed without departing from the definition of the peptide.

As used herein, the term "bridge" refers to a chemical

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bond between two amino acids in a peptide other than the amide bond by which the backbone of the peptide is formed.

As used herein, the term "peptide bond" or "peptide linkage" refers to an amide linkage between a carboxyl group of one amino acid and the α-amino group of another amino acid.

The abbreviations for amino acids are used herein are given in the following table:

Ala	Alanine
α-ABA	α-Amino isobutyric acid
Arg	Arginine
Asp	Aspartic acid
Cys	Cysteine
Glu	Glutamic acid
Gly	Glycine
Leu	Leucine
Lys	Lysine
Pen	Penicillamine
Pro	Proline
Ser	Serine
SuccAla	Succinyl-alanine

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The present invention provides novel synthetic peptides which incorporate the sequence Arg-Gly-Asp in a conformationally stabilized form. In one embodiment, the peptide comprises the sequence X-R_1-R_2-Arg-Gly-Asp-R_3-R_4-Y in which R_1 and R_4 are amino acids forming or capable of forming a bridge, such as a disulfide bridge, or a peptide linkage, R_2 and R_3 are each a sequence of 0 to 5 amino acids, X is one or more amino acids or H and Y is one or more amino acids or OH or NH_2 and together X and Y preferably total about zero to 100 amino acids, although longer sequences may also be useful. In a preferred embodiment, R_1 is penicillamine, R_4 is cysteine, R_2 is glycine and R_3 is Ser-Pro. Additional amino acids can be present at the NH_2 and COOH termini, as represented by X and Y, respectively.

Such peptides may be synthesized by any suitable method, including well-known methods of chemical synthesis. Preferably, the linear sequence is synthesized using commercially available automated peptide synthesizers. The material so synthesized can be precipitated and further purified, for example by high performance liquid chromatography (HPLC). Although a purity of greater than 95 percent for the synthesized peptide is preferred, lower purity may be acceptable.

To obtain one of the stabilized peptides of the present invention which has high specificity and affinity for particular cell surface receptors related to the cell adhesion system, the synthesized peptide is cyclized using methods well known in the art. For example, where the residues contain a sulfhydryls, a disulfide bridge may be formed by oxidizing a dilute aqueous solution of the peptide with $K_3[Fe(CN)_6]$. Other means of cyclizing which are known in the art may also be utilized.

The stabilized cyclized peptides of the present invention can also be prepared by forming a peptide bond between non-adjacent amino acid residues. A procedure for forming such peptide bond is provided in Schiller et al., Int. J. Peptide Protein Res. 25:171(1985), which is incorporated herein by reference. Briefly, cyclic peptides can be synthesized on the Merrifield resin by assembling the peptide chain using N^{α}-Fmoc-amino acids and Boc and tertiary-butyl protein.

The stabilized peptide can also be prepared by designing or treating it so as to form a helix such as an alpha (α) helix or a triple helix, according to methods well-known in the art.

The stabilized peptides described herein can be used as analogues to adhesion proteins including, for example, vitronectin. Because of the increased affinity for the

vitronectin receptor of the cyclic peptide of the preferred sequence over that of the analogous linear sequence, the cyclic peptide may be used to inhibit binding of vitronectin without affecting the function of other receptors such as the fibronectin receptor. Alternatively, the cyclic peptide can be used to promote adhesion of cells expressing the vitronectin receptor, as by coating cell culture substrates.

Certain specific structures containing an Arg-Gly-Asp sequence have been found to confer particular specificity or other attribute on the binding site. Among such structures are the sequences -Arg-Gly-Asp-NH_2, -D-Arg-Gly-Asp- and -Arg-Gly-Asp-D-Ser-. The conformationally stabilized latter sequence exhibits useful affinity for the fibronectin receptor but not the vitronectin receptor. The presence of the enantiomeric forms of the naturally occurring amino acids has been shown to confer resistance to degradation enzymes, such as trypsin, in the case of D-Arg. Other useful peptides include the sequences Phe-Arg-Gly-Asp-Ser-Pro, Gly-Arg-Gly-Asp-Ser-Phe, and Phe-Arg-Gly-Asp-Ser-Phe.

The peptides of the present invention may be utilized industrially for <u>in vivo</u> uses such as coating of medical devices, including prostheses or implants, for example vascular implants, so as to facilitate the attachment of cells thereto. In addition, the peptides have <u>in vitro</u> uses in coating of substrates, such as cell culture substrates, to promote cell adhesion.

Other features and advantages of the present invention will become apparent from the following more detailed Examples which illustrate, by way of example, the principles of the invention.

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EXAMPLE I

Peptide Synthesis

The peptide Gly-Pen-Gly-Arg-Gly-Asp-Ser-Pro-Cys-Ala was synthesized using an automated peptide synthesizer (Model 430A; Applied Biosystems, Foster City, California) according to the directions provided by the manufacturer. After cleavage from the resin with hydrogen fluoride, the peptides were washed in cold ethyl ether and precipitated from solution in trifluoroacetate with ice cold ether. The peptides were then redissolved in distilled water and lyophilized. The peptides were further purified by HPLC using a Waters Bondapak ^{TM} C_{18} (3 x 30 cm; 10 μm packing, Waters Assoc., Milford, MA).

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EXAMPLE II

Cyclization of the Peptide

611 mg of the peptide synthesized as described in Example I were dissolved in 4 liters of water that had been previously boiled and allowed to cool. Immediately prior to addition of the peptide, nitrogen was bubbled through the water for 45 minutes. After the peptide was dissolved, a solution of 0.1 μg/ml of potassium ferrous cyanide $K_3[Fe(CN)_6]$ in water was added dropwise to the stirred peptide solution until the yellow color persisted for 5 minutes (approximately 5 ml). The pH of the solution was held at 7.0 throughout this procedure by addition of NH_4OH. The solution was allowed to stand for 20 hours under low vacuum and then lyophilized. Excess $K_3[Fe(CN)_6]$ was removed by passing the cyclized material over a Sephadex G-15 column (1.8 x 120 cm). The peptide was purified by reverse phase HPLC using a Waters Bondapak^{TM} C_{18} column (3 x 30 cm; 10 μm packing) (Waters Assoc., Milford, MA). The peptide was loaded on the columnm in buffer A (20 mM ammonium acetate at pH 7.5) and eluted with a gradient of buffer B consisting of 60% acetonitrile and 40% buffer A.

Figure 1 depicts the result of purification of the cyclized peptide by reverse phase HPLC. Trace a represents purification of the peptide on the C_{18} column. Fractions 1, 2 and 3 were pooled for testing of their ability to inhibit attachment of cells to fibronectin or vitronectin. Fraction 2, containing cyclic peptide, was rechromatographed by the same procedure on a C_{18} column and yielded a single peak (trace b).

The major peak obtained from the C_{18} column (fraction 2 in Figure 1) constituted 90% of recovered peptide and was deduced to be a monomeric cyclic peptide because it was retained on the column for the length of time predicted for that sequence and because the uncyclized material and multimeric forms were well separated from the main peak.

EXAMPLE III

Formation of a Triple Helical Structure

The cell attachment promoting Arg-Gly-Asp sequence of the linear peptide generated as in Example I was conformationally restrained by allowing the peptide to assume a helical structure, according to methods of Dedhar et al, (1987) J. Cell Biol. 104:585, which is incorporated hereby reference. Briefly, a 33-amino acid peptide having the sequence $(Pro\text{-}Hyp\text{-}Gly)_4$-Ala-Pro-Gly-Leu-Arg-Gly-Asp-Thr-Gly-$(Pro\text{-}Hyp\text{-}Gly)_4$ was synthesized using an automated peptide synthesizer (Model 430A; Applied Biosystems, Foster City, CA). The sequence was confirmed by automated Edman degradation using a gas phase sequencer (Moder 470A; Applied Biosystems, Foster City, CA) as shown in Figure 3. The linear peptide was allowed to dissolve overnight in the smallest possible volume of 0.05% acetic acid at $4^{o}C$. Polarimetrical analysis was used to confirm that it had assumed a helical structure according to the method of Rhodes et al., (1978) Biochemistry, 17:3442, which is incorporated herein by reference. The peptide existed as a triple helix at low temperatures as judged by the high

degree of negative optical rotation which underwent a sharp change as the temperature was increased, producing a "melting" curve having an inflection point (second derivative equal to 0; Tm) at 30°C., as shown in Figure 4.

EXAMPLE IV

Formation of an Alpha Helical Structure

An Arg-Gly-Asp containing peptide was designed so as to have an amino acid sequence such that it would under appropriate conditions assume an alpha helical configuration. As demonstrated by Carbone et al., (1987) J. Immunology 138:1838, which is incorporated herein by reference, peptides comprising alternating α-amino-isobutyric acid (α-ABA) and alanine (Ala) residues adopt helical conformations in structure-forming organic solvents. Moreover, the presence of a negatively charged group at the amino terminus and a positively charged group at the carboxy terminus creates a dipole which acts to stabilize such a helix (Shoemaker et al., (1987), Nature 326:563, which is incorporated herein by reference). Further, the sequence of amino acids were chosen so as to create an amphiphilic secondary structure in which hydrophilic residues lie on one side, lipophilic residues on the other side of the helix (Kaiser et al., (1984) Science, 223:249, which is incorporated herein by reference).

The following linear sequence was produced by an automated peptide sequencer (Model 430A; Applied Biosystems, Foster City, CA) was: SuccAla-Leu-Glu-Glu-αABA-Ala-Lys-Arg-Gly-Asp-Ser-Leu-αABA-Gly-Lys-αABA-Ala-Lys.

The peptide was synthesized and purified according to the methods of Example 1. The alpha helical conformation of this peptide is depicted schematically in Fig. 5.

EXAMPLE V

Cell Adhesion Assay

Fibronectin and vitronectin were purified from human plasma according to the methods of Ruoslahti et al., (1982) Meth. Enz. 82:803; and Hayman et al., (1983) PNAS 80:4003, respectively, both of which are incorporated herein by reference. The adhesion of normal rat kidney cells to fibronectin and vitronectin was assayed as described in Ruoslahti et al., Meth. Enz. supra. Briefly, 0.1 ml solution of fibronectin or vitronectin at a concentration of 12 µg/ml in 0.1M PBS was placed in each well of 96-well plastic microtiter plates and left for 2 hours at room temperature. The unattached protein was removed by washing three times with PBS.

One day before the assay, a confluent culture of normal rat kidney cells was split 1:2 using standard tissue culture trypsin. The cells were washed three times with PBS, pH 7.2. 10 ml of 2 x crystallized trypsin (Sigma, Type III), 0.1 mg/ml in PBS, was added, and the cells incubated at 37°C until they detached. The detached cells were then collected by centrifugation and washed three times with a solution of 0.5 mg/ml of soybean trypsin inhibitor in PBS to ensure neutralization of the trypsin. Before the last centrifugation, a sample was taken and cell numbers and viability by trypan blue exclusion are determined. The cells were suspended in minimal essential medium (MEM) at a concentration of 10^6 cells/ml and dispersed by pipetting until a single-cell suspension was obtained.

To ensure even dispersal of the cells in the microtiter well, 0.1 ml of MEM was added to each well, followed by the addition of 0.1 ml of the cell suspension. The plate was incubated for 1 hour at 37°C.

The unattached cells were removed simply by removing the

medium and washing the wells. The plate was flooded with PBS, and the washing solution was removed. The cells were then fixed with 3% paraformaldehyde in PBS and stained with 1% toluidine blue, paraformaldehyde in PBS, and attached cells counted. Their number was determined using a cell counter that is capable of counting cells attached to a surface (Dynatech Laboratories, Alexandria, VA).

The ability of the cyclized peptide of the invention to inhibit adhesion of cells to the substrates was assayed by adding stock solutions of the peptide dissolved in MEM to give final concentrations in the wells of 0 to 10.0 mM. Prior to addition to the assay, the stock solutions were neutralized with sodium bicarbonate. Rat kidney cells were added and the wells incubated and assayed as described.

In order to more fully determine the ability of the cyclized peptide to inhibit the attachment of normal rat kidney cells to the fibronectin and vitronectin substrates, the binding of a non-cyclized, or linear, peptide having the sequence Gly-Pen-Gly-Arg-Gly-Asp-Ser-Pro-Cys was assayed. As shown in Figure 2, the cyclic peptide of the invention inhibited attachment to vitronectin at a 10-fold lower molar concentration than the linear peptide, but it was ineffective at inhibiting attachment to fibronectin. The linear peptide, in contrast, inhibited attachment of cells to both substrates at relatively similar concentrations.

While not wishing to be bound by this explanation, the cyclic peptide of the invention appears to possess a different affinity for the binding site of fibronectin and vitronectin receptors. This is consistent with the fact that the rat kidney cells used in the assay are known to possess separate receptors for fibronectin and vitronectin.

EXAMPLE VI

Cyclization Through Peptide Bond

The peptide cyclo-(1-7)Gly-Arg-Gly-Asp-Ser-Pro-Asp-Gly was synthesized using a modification of the method of Schiller et al., Int. J. Peptide Protein Res. 25:171 (1985), which is incorporated herein by reference.

The synthesis was done using PAM resin-TFA; (Applied Biosystems, Inc., Foster City, CA) with t-Boc Gly-attached to the resin withd a substitution factor of 0.80 mmol/g (see Figure 6). All amino acids were obtained from Bachem Bioscience, Inc., Philadelphia, PA. 1.25 g (1.0 mmol) of resin was shaken with 20 ml dichloromethane (DCM) for 15 minutes to induce swelling and DCM removed with N_2 pressure the procedure repeated. The t-Boc protecting group was cleaved with 20 ml 20% TFA; (Applied Biosystems, Inc., Foster City, CA) in DCM (Pfizer, Groton, CN) for 15 minutes. This reaction was repeated, this time shaking for 30 minutes. Between the reactions, the resin was washed once with 20 ml DCM for 2 minutes. After the second reaction, the resin was washed six times with 20 ml DCM for 2 minutes each, followed by neutralization with 20 ml 10% triethylamine (TEA) in DCM two times for 3 minutes each. The resin was washed six times with 20 ml DCM for 2 minutes each and was then ready for the next reaction.

In a 50 ml round bottom flask equipped with stirring bar, Fmoc-Asp-t-butyl ester ((OtBu)OH) (1.03 g, 2.5 mol) was dissolved in 15 ml DCM followed by addition of 2.5 ml (1M) DIC (Aldrich Chem. Co., Milwaukee, WI) in DCM. The mixture diisopropyl carbodiimide was stirred for 5 minutes and followed by addition of 1.25 ml 2.0 M hydroxybenzotriazole (HOBT; Aldrich) in DMF (Pfizer) at 0°C and stirred for 10-15 minutes more. This mixture was added to the resin and shaken 1 to 2 hours. This reaction was repeated once (double coupled) and the resin was washed 2 times with 20 ml DCM between couplings. After the second

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coupling was completed, the resin was washed three times with 20 ml DCM.

The cleavage of the Fmoc group was done with 20 ml 20% piperidine (Aldrich) in DCM (freshly made) and shaken for 15 minutes. This reaction was repeated for another 30 minutes. The resin was then washed once with DMF and five times with DCM for 2.0 minutes each. Then the resin was ready for the next coupling.

In a 50 ml round bottom flask equipped with stirring bar, Fmoc-Pro-OH (0.84 g, 2.5 mmol) was dissolved in 15 ml DCM followed by addition of 2.5 ml (1 M) DIC in DCM. The mixture was stirred for 5.0 minutes, followed by the addition of 1.25 ml (2M) HOBT in DMF at 0°C and stirred for 10 to 15 minutes more. This mixture was added to the resin and shaken 1 to 2 hours. This reaction was repeated once (double coupled) and the resin was washed 2 times with 20 ml DCM between couplings. After the second coupling was completed, the resin was washed three times with 20 ml DCM. The Fmoc was cleaved using the same procedure as above and the material was then ready for the next coupling.

In a 50 ml round bottom flask equipped with stirring bar, Fmoc-Asp-benzyl ester ((OBzl)-OH) (1.11 g, 2.5 mmol) was dissolved in 15 ml DCM followed by addition of 2.5 ml (1 M) DIC in DCM. The mixture was stirred for 5.0 minutes, followed by addition of 1.25 ml 2.0 M HOBT in DMF at 0°C and stirred for 10 to 15 minutes. This mixture was added to the resin and shaken 1 to 2 hours. This reaction was repeated once (double coupled) and the resin was washed 2 times with 20 ml DCM between couplings. After the second coupling was completed the resin was washed three times with 20 ml DCM. The Fmoc was cleaved using the same procedure as above and the material was then ready for the next coupling.

In a 50 ml round bottom flask equipped with stirring bar, Fmoc-Gly-OH (0.74 g, 2.5 mmol) was dissolved in 15 ml

DMF followed by addition of 2.5 ml (1 M) DIC in DCM. The mixture was stirred for 5.0 minutes, followed by addition of 1.25 ml 2.0 M HOBT in DMF at 0°C and stirred for 10 to 15 minutes more. This mixture was added to the resin and shaken 1 to 2 hours. This reaction was done twice (double coupled) and the resin was washed 2 times with 20 ml DCM in between coupling. After the second coupling was completed the resin was washed three times with 20 ml DCM. The Fmoc was cleaved using the same procedure as above and the material was then ready for the next coupling.

In a 50 ml round bottom flask equipped with stirring bar, Fmoc-Arg Tosilate ((Tos)OH) (1.37 g, 2.5 mmol) was dissolved in 15 ml DCM followed by addition of 2.5 ml (1M) DIC in DCM. The mixture was stirred for 5.0 minutes and followed by addition of 1.25 ml 2.0 M HOBT in DMF at 0°C and stirred for 10 to 15 minutes more. This mixture was added in to the resin and shaken 1 to 2 hours. This reaction was repeated once (double coupled) and the resin was washed 2 times with 20 ml DCM in between coupling. After the second coupling was done the resin was washed three times with 20 ml DCM. The Fmoc deprotection was performed using the same as the procedure above and the material was then ready for the next coupling.

In a 50 ml round bottom flask equipped with stirring bar, t-Boc-Gly-OH (0.44 g, 2.5 mmol) was dissolved in 15 ml DCM followed by addition of 2.5 ml (1M) DIC in DCM. The mixture was stirred for 5.0 minutes and followed by addition of 1.25 ml (2M) HOBT in DMF at 0°C and stirred for 10 to 15 minutes more. This mixture was added in to the resin and shaken 1 to 2 hours. This reaction was repeated (double coupled) and the resin was washed 2 times with 20 ml DCM in between coupling for 2 minutes each. After the second coupling was done the resin was washed three times with 20 ml DCM for 2 minutes each.

The deprotection of the t-Boc Group of Gly 1 and the t-Butyl ester side chain of Asp 7 was performed at the same

time by adding 20 ml 20% TFA in DCM for 15 minutes. This reaction was repeated once again for 30 minutes. Between reactions the resin was washed once with DCM for 2 minutes. After the second reaction, the resin was washed six times with 20 ml DCM for 2 minutes each, followed by neutralization with 20 ml 10% TEA in DCM two times for 3 minutes each. The resin was washed six times with 20 ml DCM for 2.0 minutes each.

The N-terminus of Gly 1 was cyclized to the side chain carboxyl group of Asp 7. The cyclization was accomplished by adding 10 ml of 1M DIC solution and 5 ml 2M HOBT in DMF and shaken for 4 days. Each day, old reagent was drained and the resin was washed with 20 ml DMF once and with DCM three times for 2 minutes each. Fresh reagent (DIC and HOBT) was then added.

The resin was cleaved with hydrogen fluoride using procedures well known in the art. After cleaving, the peptide-containing resin was were washed with cold ethyl ether then dissolved with 10% acetic acid to remove the peptide from the resin. The filtrate was frozen and lyophilized. The crude product recovered was 508 mg. This crude product was subjected to purification using HPLC through C_{18} (1 X 20 cm; 10-μm packing) column. The peptide was loaded on the column in buffer A (10 mM ammonium acetate at pH 6.0) and eluted with a gradient of buffer B consisting of 60% acetonitrile and 40% buffer A. Yield after purification was 210 mg.

This compound was confirmed to have the desired cyclic peptide structure by proton NMR in DMSO-d6 as the solvent. The 1D and 2D (COSY, COSY-Relay, and NOESY) spectra of this compound were obtained by using a 360 MHz FT-NMR equipped with Nicolet software at the University of California, San Diego NMR facility. (See Wuthrich, K., NMR of Proteins and Nucleic Acids, John Wiley & Son, NY (1986), which is incorporated herein by reference).

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Although the invention has been described with reference to the presently-preferred embodiment, it should be understood that various modifications can be made by those skilled in the art without departing from the invention. Accordingly, the invention is limited only by the following claims.

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